Miniature Echelle Grating Spectrometer Cartridge

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Current missile defense systems do not identify the content of an intercepted warhead payload. Spectral sensors could be used to “type” the intercepted warhead based on detection of key optical signatures of warhead components. An optimal platform for such a sensor is the last stage of the booster that releases the kill vehicle. To be compatible with this platform, a tenfold reduction in size, weight, and power is required over current generation systems. We can accomplish this miniaturization by merging proven cross-dispersive spectrographic techniques with compact engineering approaches applied to other remote sensing projects.

Using an echelle spectrograph, which disperses light in two orthogonal directions to efficiently fill a 2-D focal plane, high spectral resolution is attained in relatively high frame rates. Size reduction is achievable using a multipass architecture and immersion grating techniques.

Project Goals

This project performs initial scoping and exploration of a compact opto-mechanical configuration for an echelle spectrograph that has the high strategic potential of performing real-time, remote-target forensics on warheads as they are being destroyed. We focus on the mid-wave infrared band for this study, with an approach that is extendable to other infrared bands, to collect potential nuclear warhead signatures of uranium, plutonium, tritium, and their potential compounds (see Fig. 1).

After down-selecting optical systems that meet these requirements, we sought to define precision mounts that maximize use of an existing cartridge-style mechanical infrastructure. This supports the vision of a relatively modest incremental investment of a new optical cartridge and controls that creates a completely new instrument. The final product is a feasible solution for an echelle spectrograph optical cartridge, including optical prescriptions, performance predictions, an FPA technology assessment, and an opto-mechanical cartridge packaging concept.

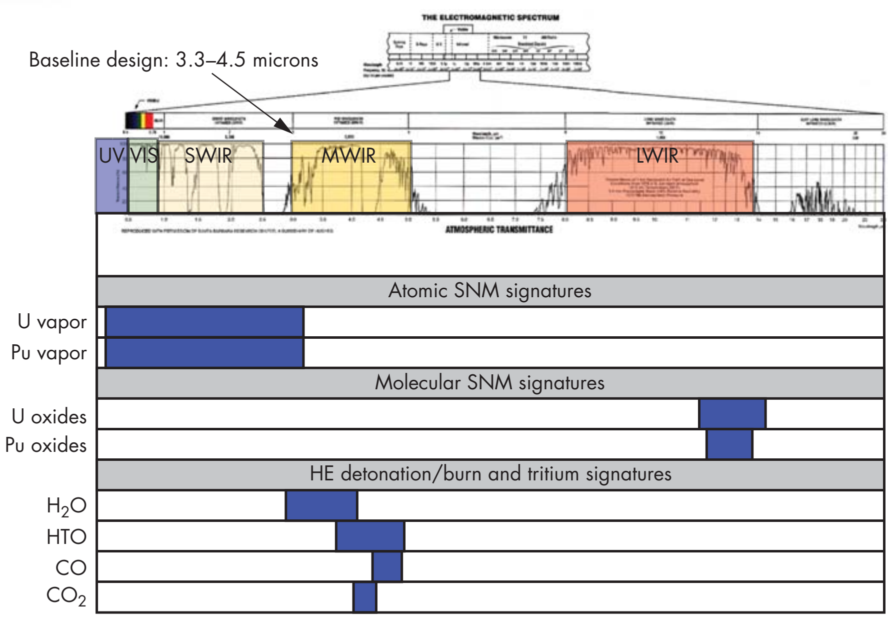

Figure 1. Locations of infrared emission spectra for nuclear warhead material signatures.

Figure 2. Nighttime missile launch at Vandenberg Air Force Base.

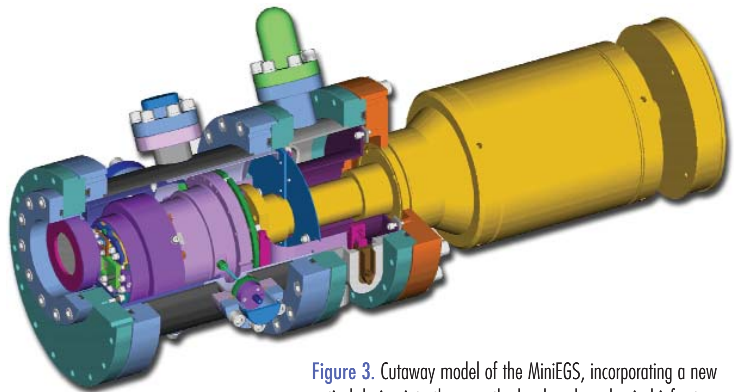

Figure 3. Cutaway model of the MiniEGS, incorporating a new optical design into the recently developed mechanical infrastructure of a hyperspectral imaging spectrometer.

Relevance to LLNL Mission

LLNL's national security mission requires special multidisciplinary capabilities that are also used to pursue programs in advanced defense technologies. Potential users include the U. S. Missile Defense Agency for warhead typing (see Fig. 2), Strategic Command, and the Special Operations Command for interdiction consequence assessments. The small form factor also makes this sensor attractive for other applications requiring high spectral resolution and low volume, weight, and power.

FY2004 Accomplishments and Results

In accordance with our project plan, the optical arrangement options that were considered were intentionally biased toward recent advances in miniaturizing hyperspectral instrument packaging infrastructure (dewar, vacuum system, cryogenic system).

A feasible optical solution was verified to have the required optical performance in the highly compact form factor (see Fig. 3). Optical volume was reduced by a factor of 60. With a spatial image format of 3 × 3, an F-number of 4, and a 256-×-256-pixel detector array of 30-μm pixels, we verified that the diffraction-limited model meets the waveband requirement of 3.3 to 4.5 μm, and spectral resolution of 0.27 cm^{-1}. Infrared emission spectra for nuclear warhead materials were identified. For the mid-wave version studied, spectral signatures of high explosive detonation and tritiated water fall within the sensor passband.

FY2005 Proposed Work

Further optimization of the wavelength range will tailor the baseline system toward signatures of interest. Diffraction efficiency checks will determine transmittance vs. wavelength. Reformatting the 3-x-3 array to a 9-x-1 array for the sensor entrance slit will require additional optical elements directly in front of the entrance slit. A preliminary optical tolerance study will be performed.

Commercial off-the-shelf focal plane array technologies will be investigated for feasibility at this form factor. A mechanical study will determine the extent that the existing hyperspectral optical cartridge can be used to build a new cross-dispersive system, and immersion gratings will be checked for manufacturability. New concepts will be generated based on this gap analysis, to determine the complete scope of the effort needed for a prototype system.